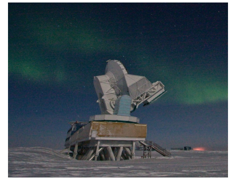
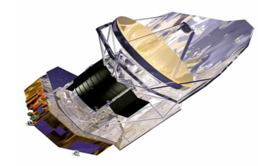



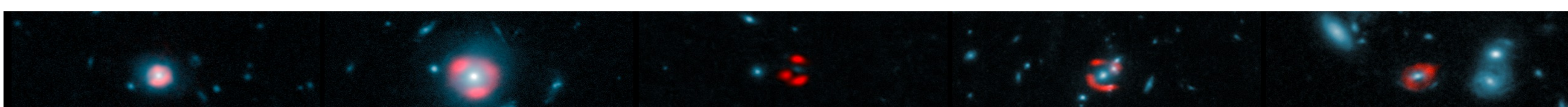



Resolved CO observations of two lensed dusty star-forming galaxies out to z=6

Manuel Aravena (U. Diego Portales), Justin Spilker (U. Arizona)
SPT-SMG collaboration

Talk mostly based on Spilker et al. (2015; ApJ, to be submitted)

ESO Dissecting Galaxies Near and Far: High resolution views of Star Formation and the ISM workshop – Santiago, March 2015



Dusty star-forming galaxies at high-z discovered in FIR/mm surveys

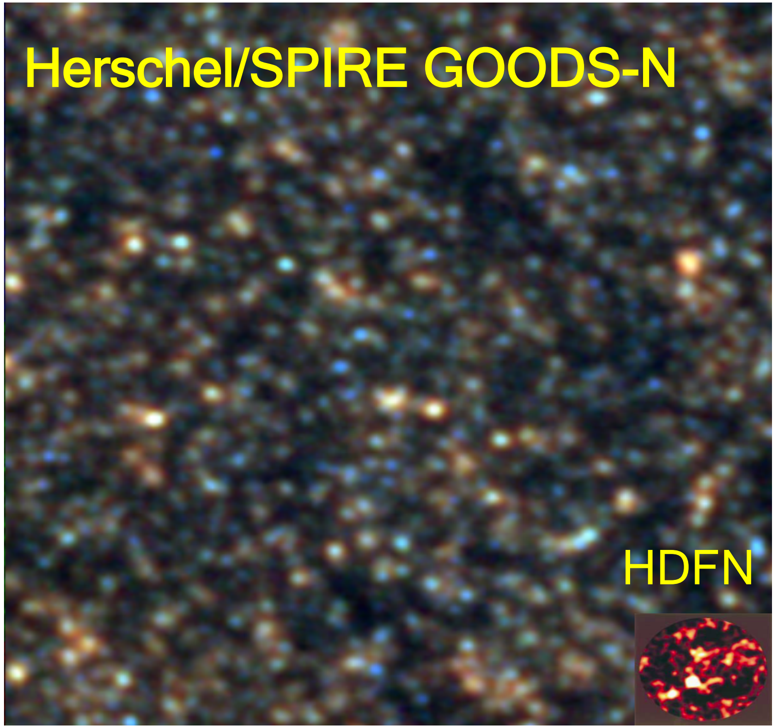


Fig. Herschel/SPIRE FIR map of the a section of the GOODS-North field (Oliver et al. 2010).

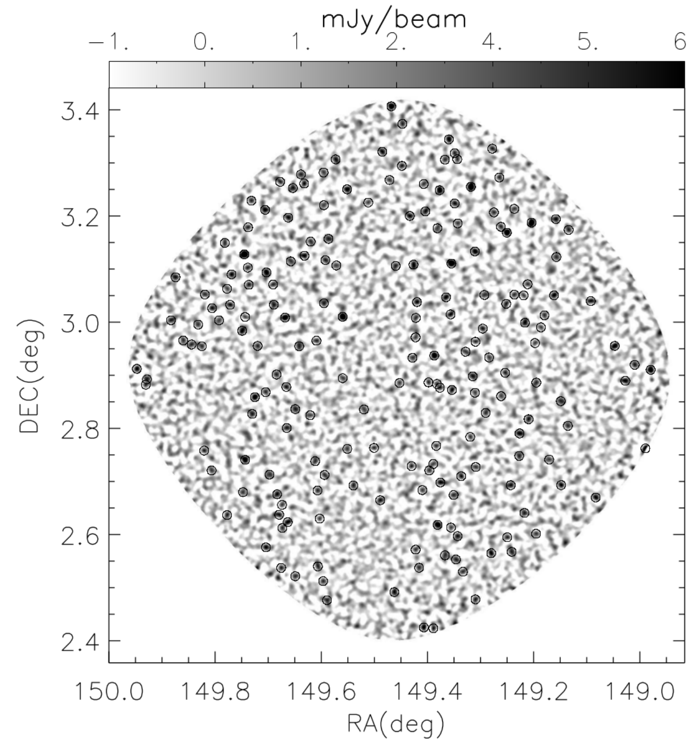


Fig. AzTEC 1.1mm map of the COSMOS field (Arextaga et al. 2012).

The South Pole Telescope mm-wave survey

- One of the latest large mm surveys was conducted with the SPT
- Surveyed 2500 deg^2 in 3 bands: 3mm, 2mm and 1mm (Vieira et al. 2010; Mocanu et al. 2013).
- About 100 mm bright sources consistent with strongly lensed SMGs at $S_{1.4mm}$ > 20 mJy

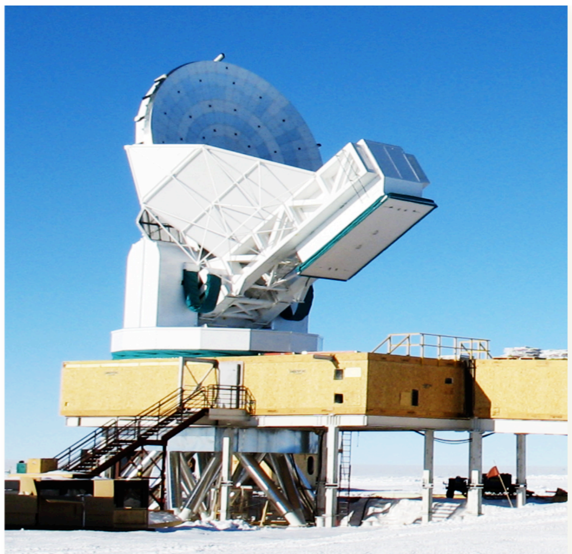


Fig. The South Pole Telescope.

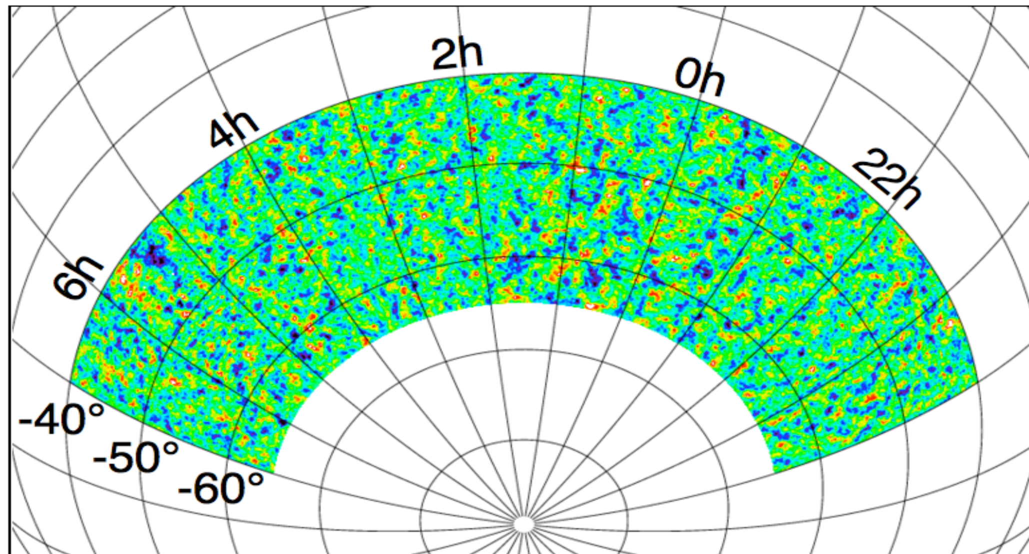


Fig. Millimeter map of the region covered by the SPT survey.

- SPT covers large area of the sky being sensitive to the brightest objects.
- Due to negative k-correction at mm wavelengths it shows a flat redshift selection
- SPT mm number counts indicate all objects are strongly lensed.

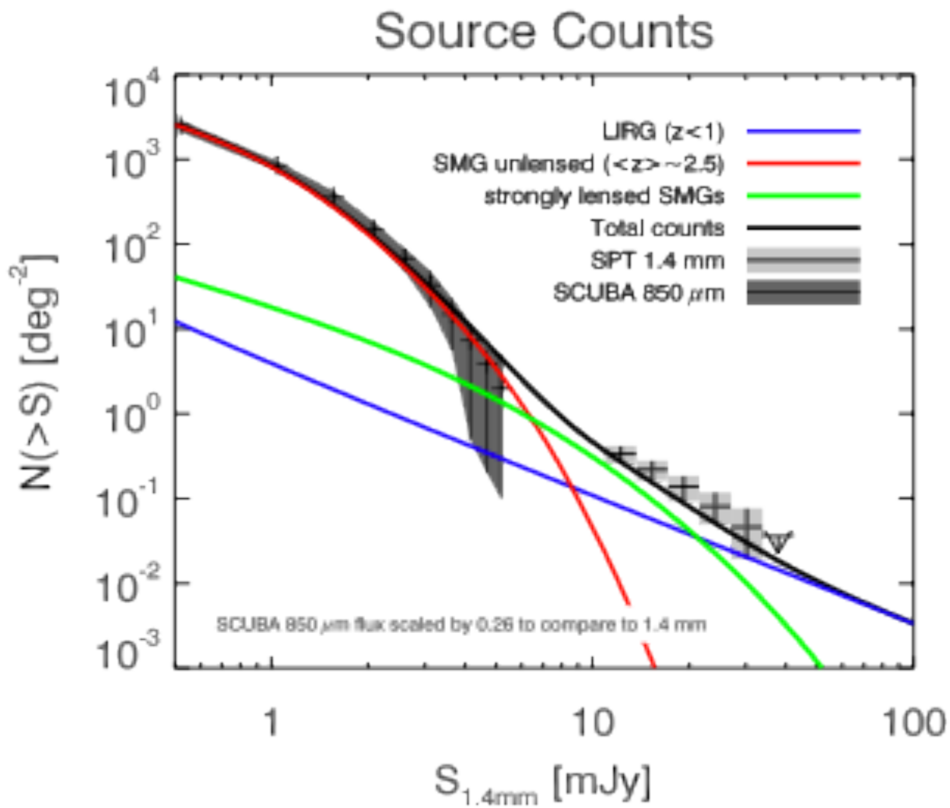


Fig. Millimeter number counts for SPT sources compared to counts measured in unlensed SMGs, and models of LIRGs and lensed SMGs.

High-redshift, bright sources: Unique sample!
(Vieira et al. 2010)

Questions

- Starburst vs main-sequence galaxies?: abundance and dominance
  (e.g. Sargent et al 2012, 2014; Bethermin et al. 2012, 2014)

- Are the most luminous systems real progenitors of compact red galaxies or local ellipticals?
  (e.g. Toft et al. 2013)

- Cosmic evolution of these galaxies: z distribution, cosmic SFR and gas density, etc
- (Smolcic et al. 2012; Weiss et al. 2013; Sargent et al; Walter et al. 2014)

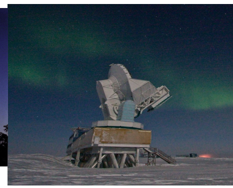
- Nature and ISM properties of galaxies: Spatial distribution of stars, SF and gas; gas excitation
  (e.g. Carilli & Walter 2013)

- Many questions can be addressed by taking advantage of the magnification of gravitationally lensed sources

Multi-wavelength follow-up campaign

ATCA

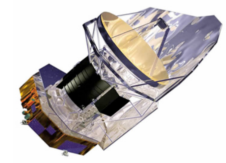
SPT



APEX

ALMA

Herschel



VLT

HST

- Ambitious follow-up campaign with all major observatories.
- Determine crucial parameters for the characterization of the sources: redshifts, lens models (VLT, Gemini, Magellan, HST, Spitzer)
- Constrain the different components of their host galaxies: star-formation, dust, gas and stars (ALMA, ATCA, APEX, Herschel, SMA)

ALMA 870μm high-resolution imaging

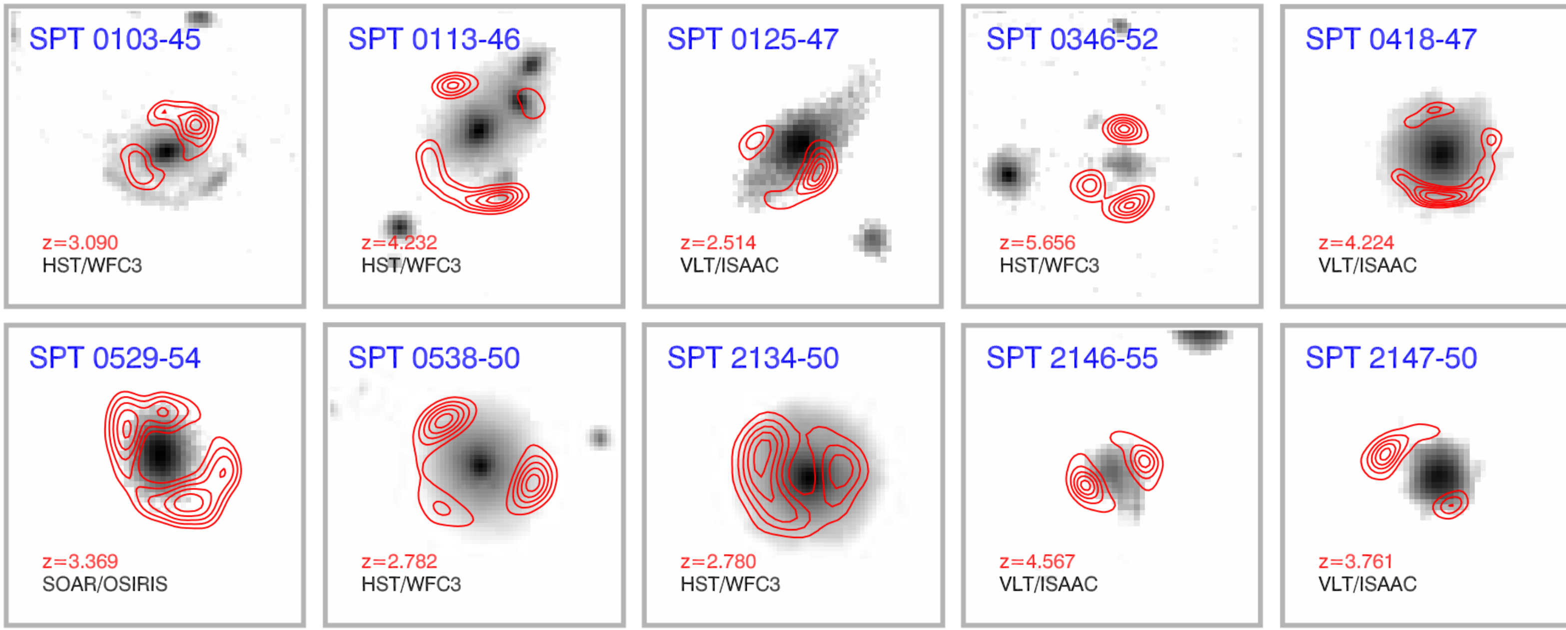


Fig. ALMA 870um imaging of SPT SMGs. Optical/NIR images from HST or VLT are shown in the background with red contours overlaid showing the ALMA 870um emission from the background lensed source.

Vieira et al. (2013), Nature, 495, 344
Hezaveh et al. (2013), ApJ, 767, 132

First blind CO redshift survey with ALMA

ALMA Band 3 - 26 sources - 5 tunings covering the full 3 mm band

(Vieira et al. 2013, Nature; Weiss et al. 2013, ApJ, 767, 88)

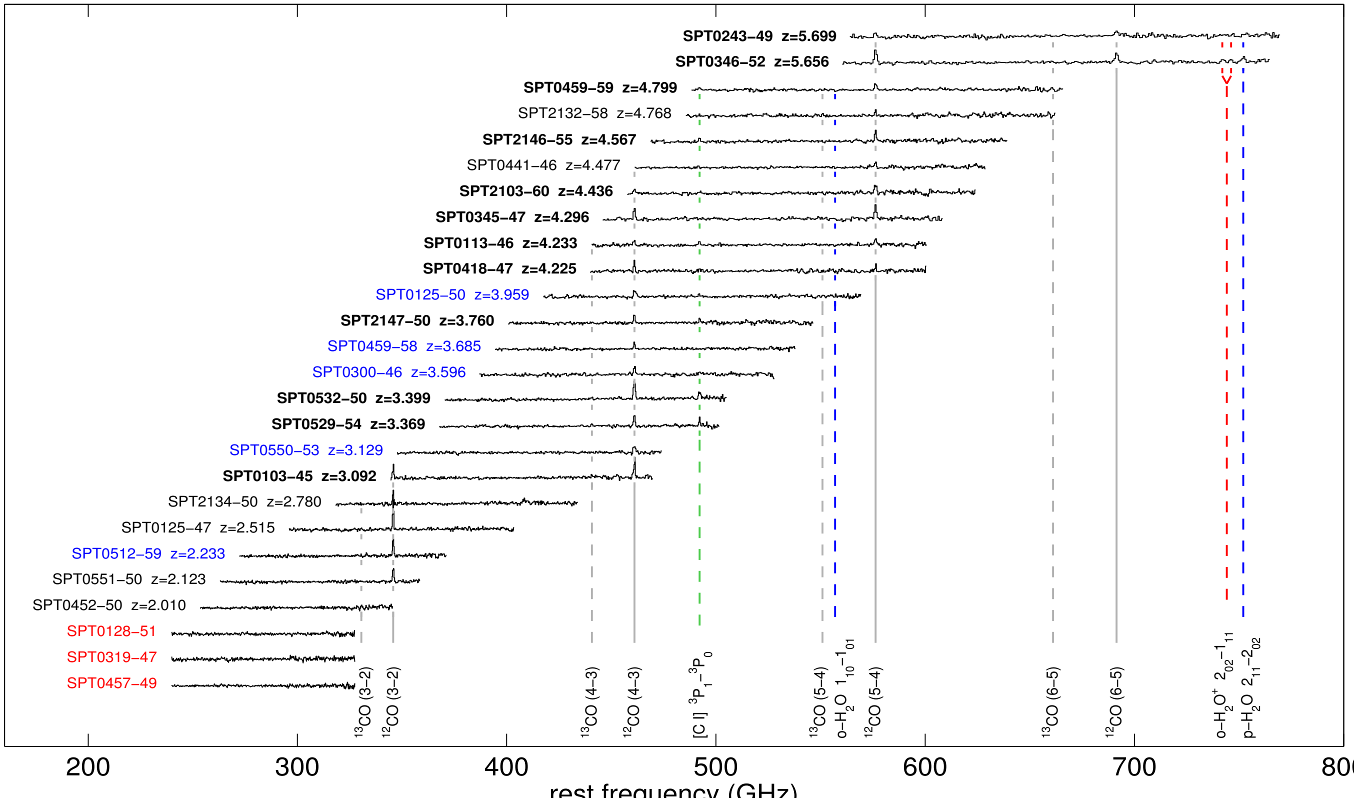


Fig. Rest-frame submm spectra toward a sample of 26 SPT SMGs obtained with ALMA in cycle-0. The main molecular emission lines detected are highlighted with vertical lines.

Composite submm spectrum of dusty starburst galaxies at high-z

(Spilker et al. 2014, ApJ, 785, 149)

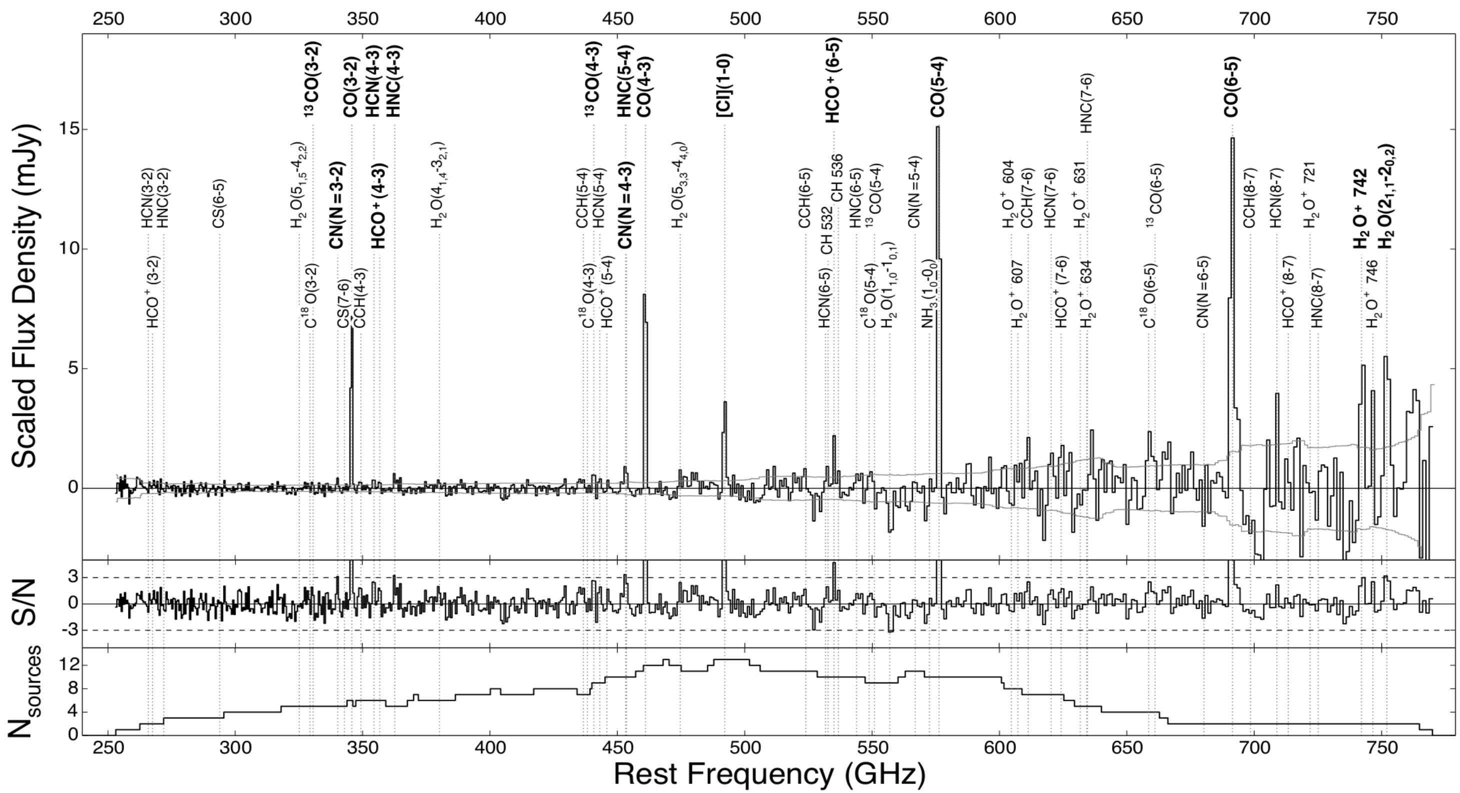
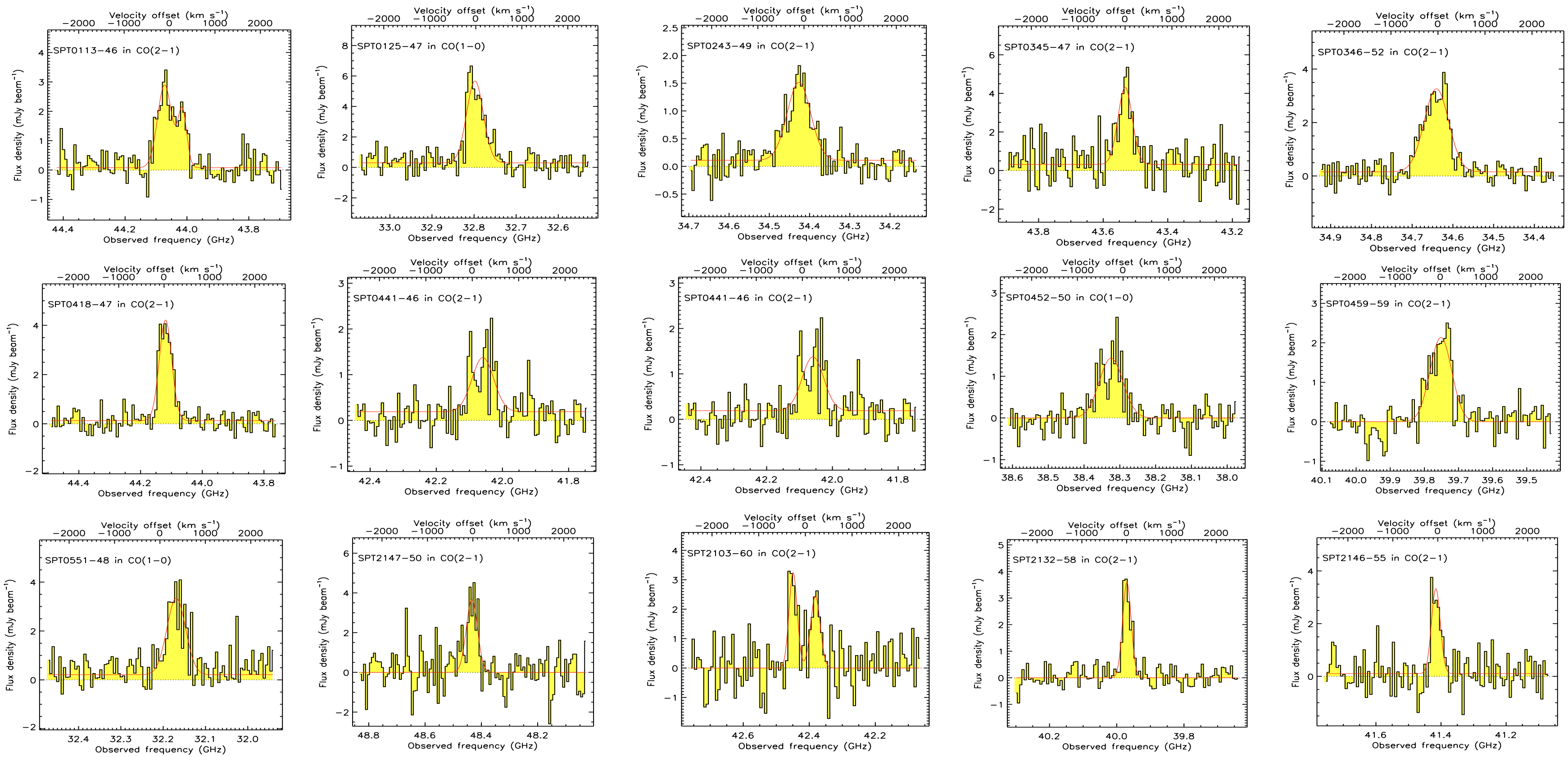


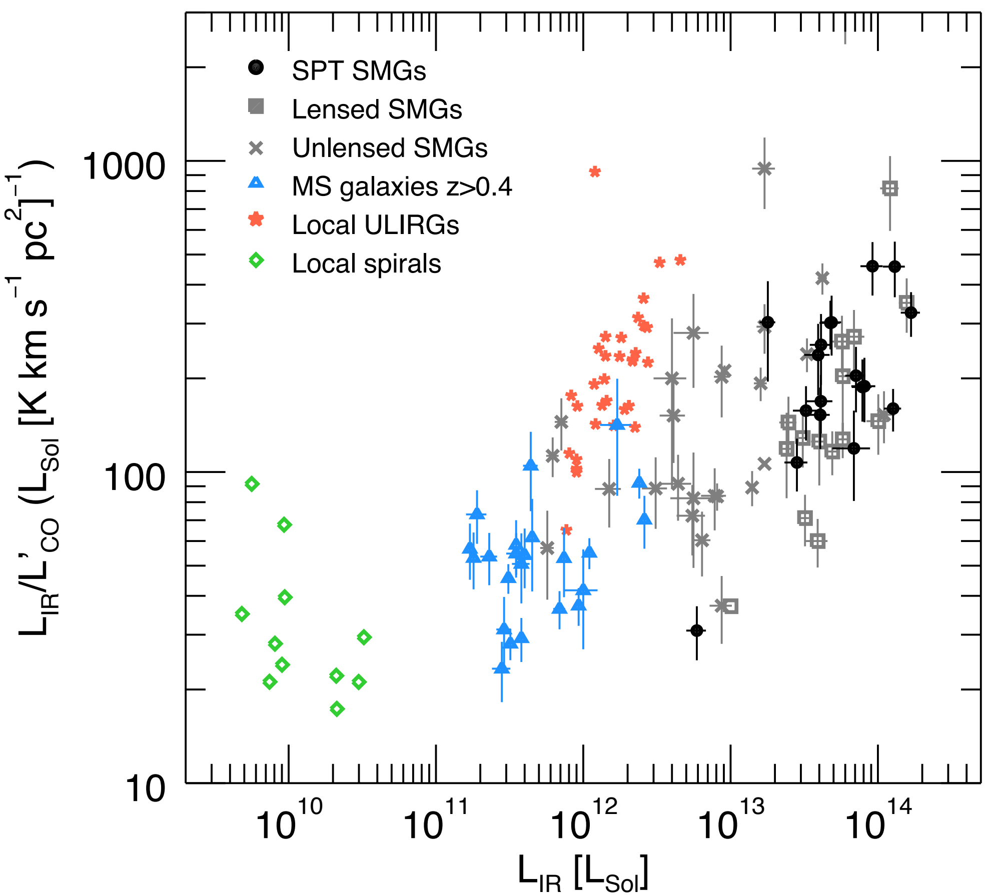
Fig. Composite FIR-to-mm spectrum, constructed from the stack of 22 high-z SPT SMGs at a resolution of 500 km/s and normalized to z=3 and $S_{1.4mm}$ = 15 mJy.

CO (*J=1-0, 2-1*) survey of SPT DSFGs with ATCA



(Aravena et al. 2013; Aravena et al. in prep.)

Low-*J* CO (*J=1-0, 2-1*) survey of SPT star-forming galaxies



Most SPT SMGs are not detected in HST/Spitzer images due to obscuration, making it hard to compute stellar masses.

Are they MS galaxies or merger/starburst?

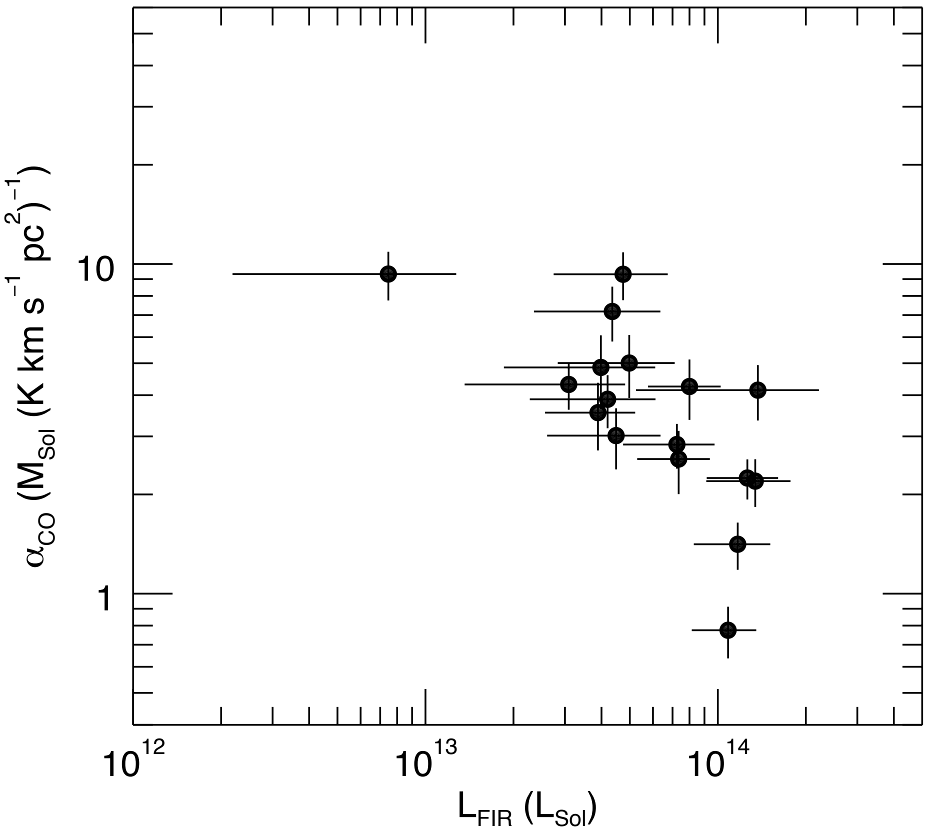
Need to investigate their properties by other means.

Fig. L_{IR} vs L'_{CO} for SPT SMGs compared to other galaxy samples.

Aravena et al. in prep.

Low-*J* CO (*J=1-0, 2-1*) survey of SPT star-forming galaxies

Comparison of dust-based ISM masses and L'_{CO} can lead to measurement of α_{CO}

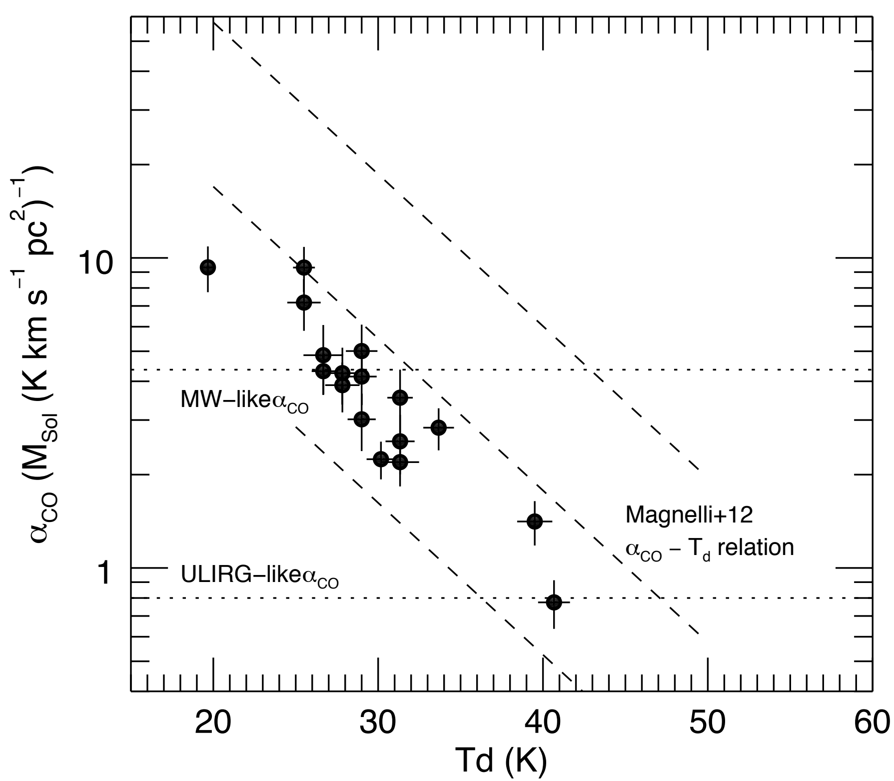


$M_{ISM,\ dust} = M_{ISM,\ CO} = \alpha_{CO}\ L'_{CO}$

Derived α_{CO} values in range 2-10, similar to values derived for MS galaxies (Magnelli et al. 2012).

ATCA low-J CO survey of SPT SMGs

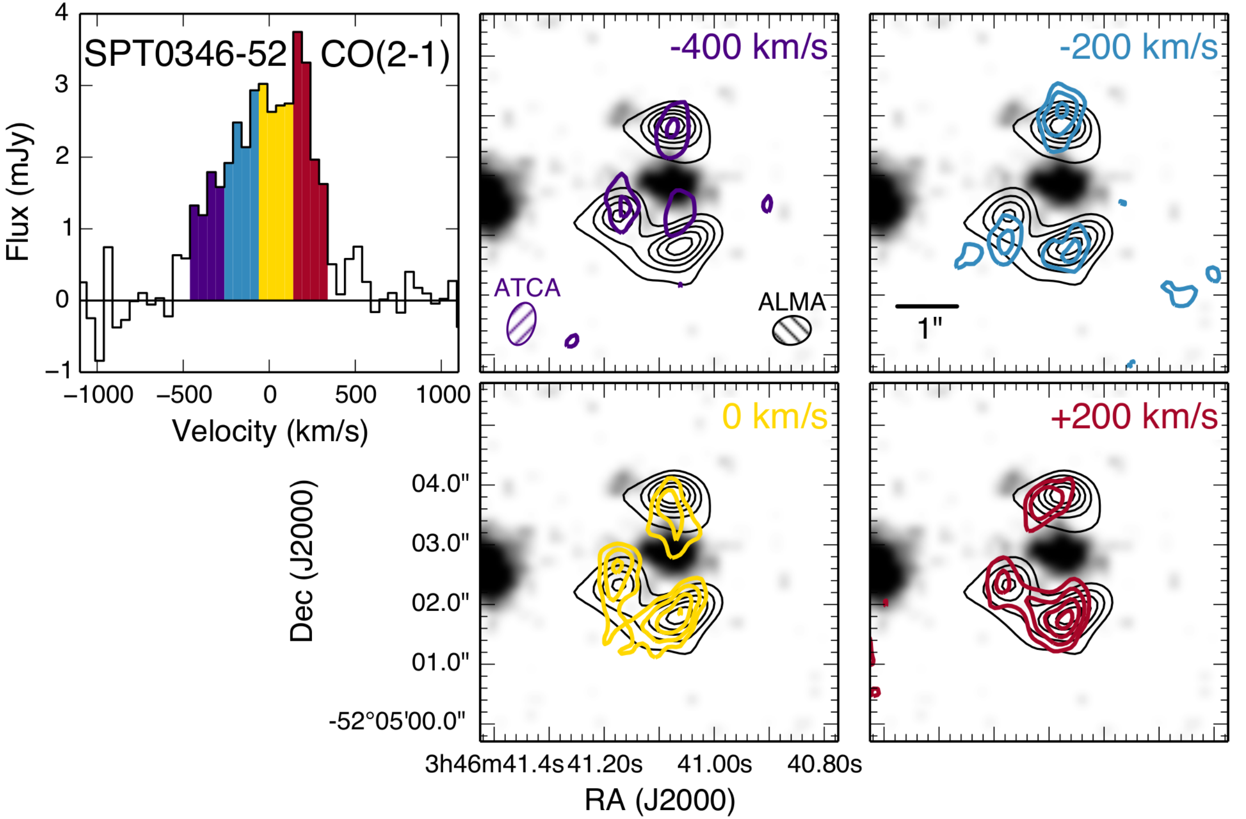
Comparison of dust-based ISM masses and L'_{CO} can lead to measurement of α_{CO}



$M_{ISM,\ dust} = M_{ISM,\ CO} = \alpha_{CO}\ L'_{CO}$

Derived α_{CO} values in range 2-10, similar to values derived for MS galaxies (Magnelli et al. 2012).

High-resolution CO imaging program toward SPT SMGs

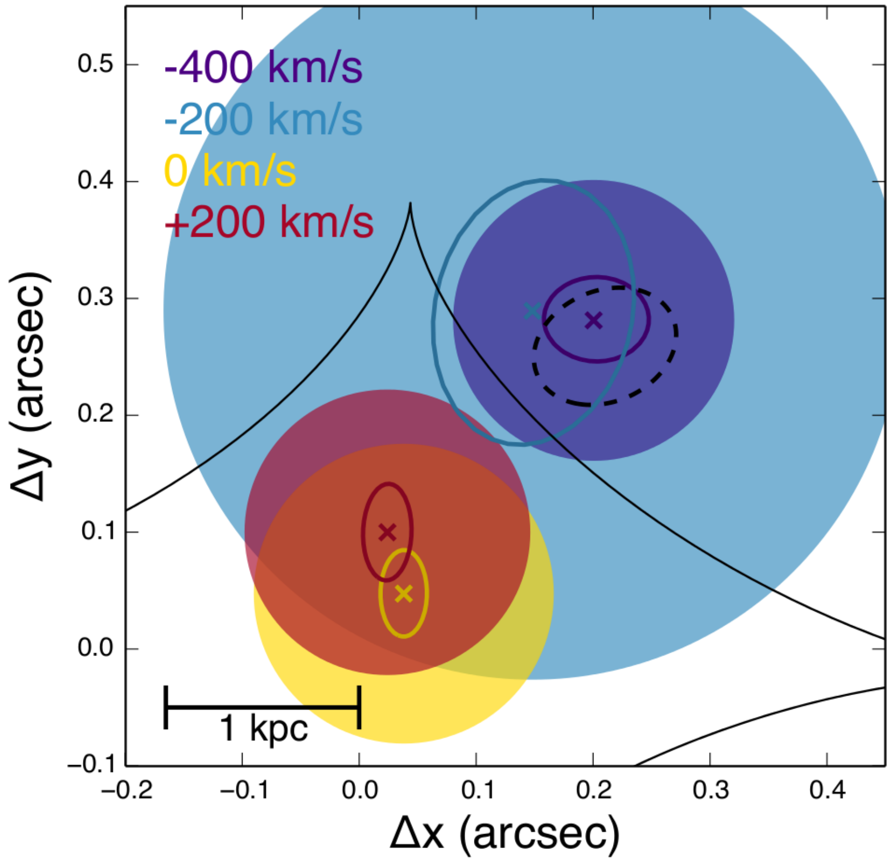


SPT0346-52 at z=5.7

- Most luminous and distant source in our sample
- Lens model indicates a compact merger

Spilker et al. 2015 (in preparation)

High resolution CO imaging program toward SPT SMGs

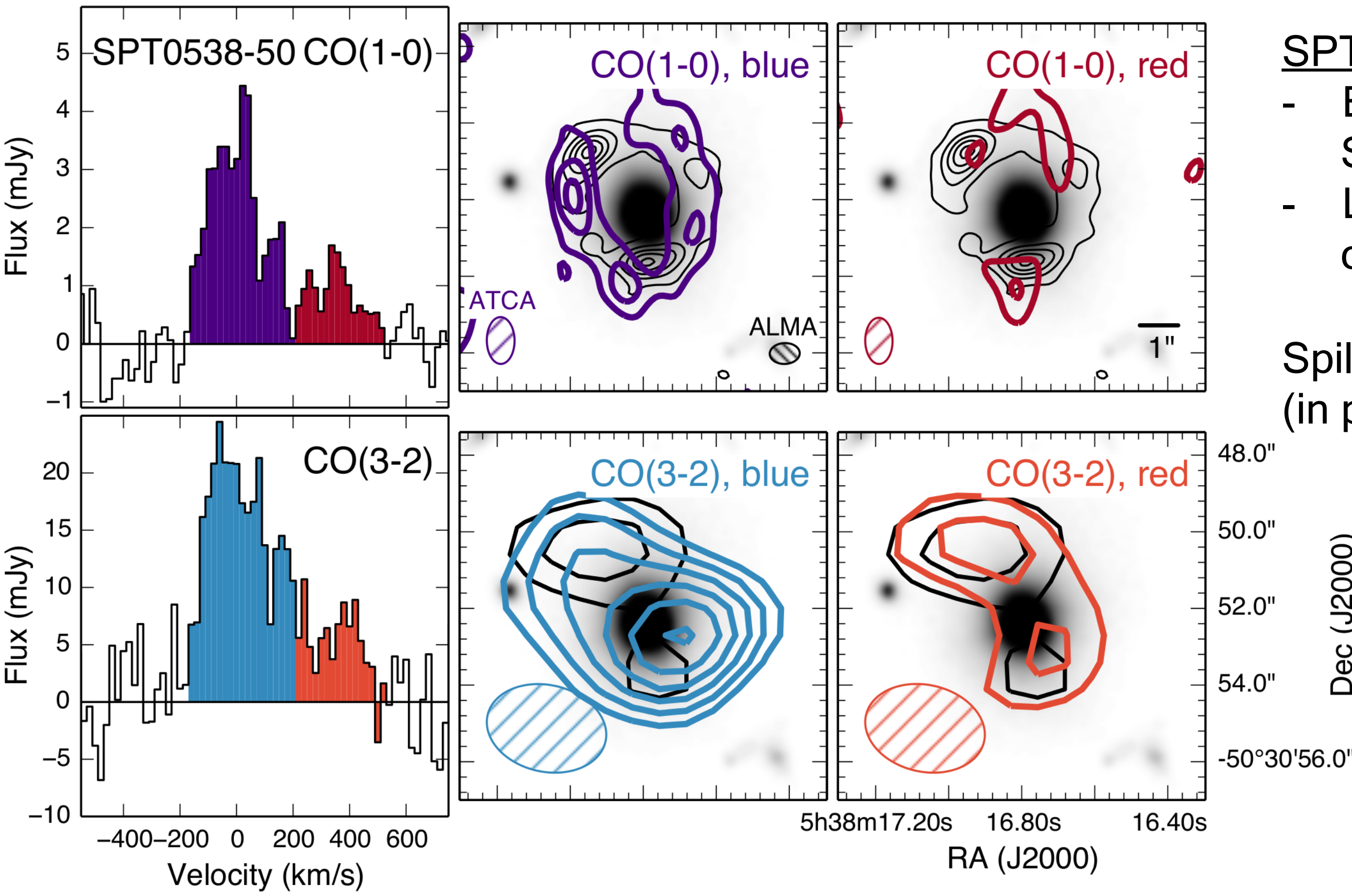


SPT0346-52 at z=5.7

- Most luminous and distant source in our sample
- Σ_{SFR} approaches Eddington limit
- Lens model indicates a compact merger

Spilker et al. 2015
(in preparation)

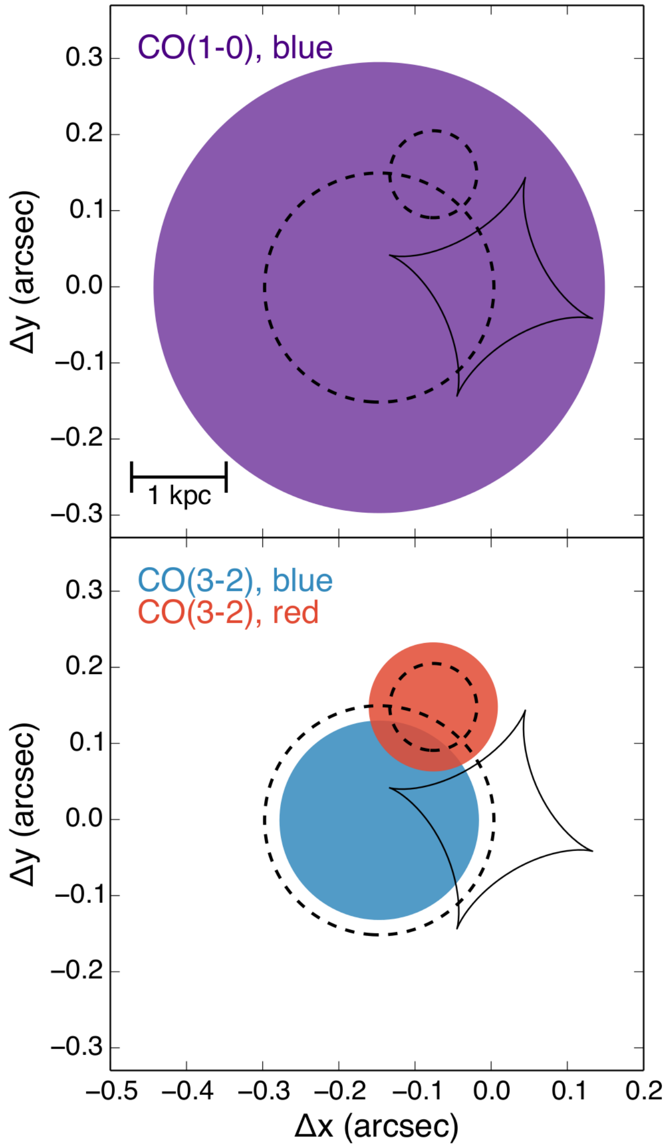
High resolution CO imaging program toward SPT SMGs



SPT0538-50 at z=2.8

- Best studied source in the SPT sample
- Lens model indicates a compact merger

Spilker et al 2015 (in preparation)



<u>SPT0538-50 at z=2.8</u>

- Best studied source in the SPT sample
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Spilker et al 2015
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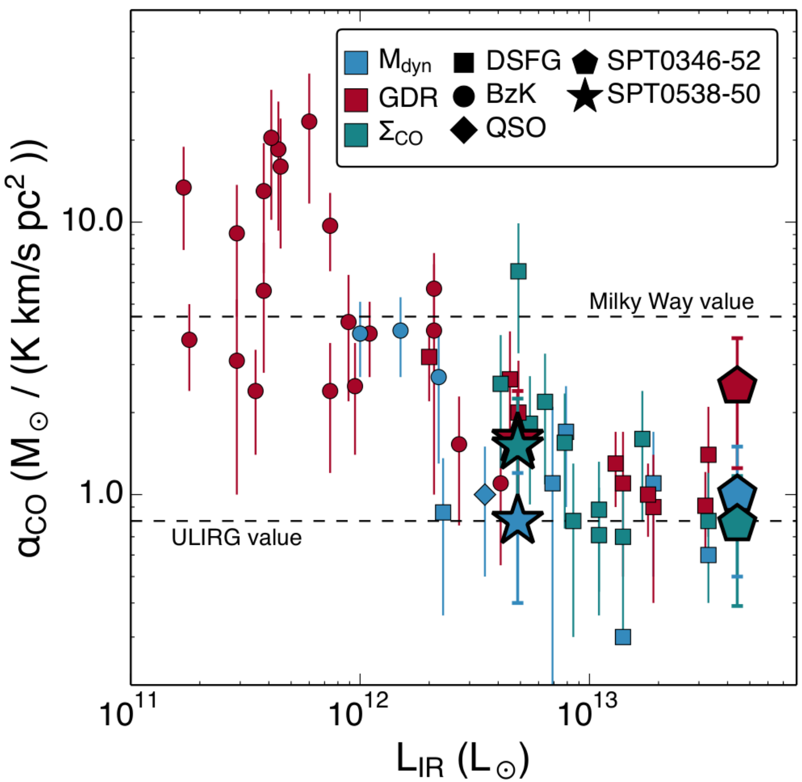
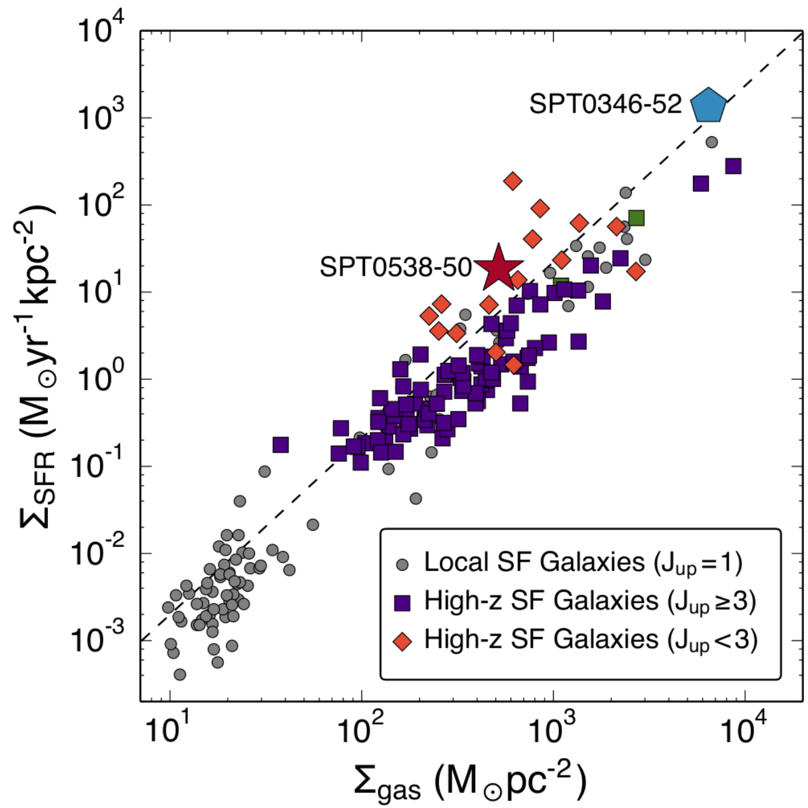
High resolution CO imaging program toward SPT SMGs





Low α_{CO} factors for both sources.

Spilker et al. (2015)

Conclusions

- We investigated the properties of the ISM in gravitationally lensed SPT dusty star forming galaxies

- We find high star formation efficiencies for the whole sample, yet CO-to-H2 conversion factors ranging from 2 to 10.

- High resolution imaging in two sources reveals that the cold molecular gas traced by CO(1-0/2-1) is more extended than the dust continuum and the gas traced by CO(3-2). Both sources are consistent with disturbed morphology, one of them consistent with merger.

- Both objects present low α_{CO} factors, but they tend to lie within the scatter of the Kennicutt-Schmidt relation.